Spin Effects in Magnetotransport of 2DES Near Vicinal Silicon Surface

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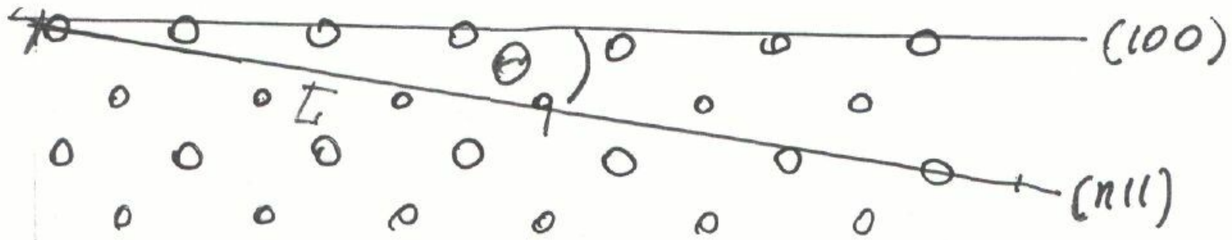
Outline

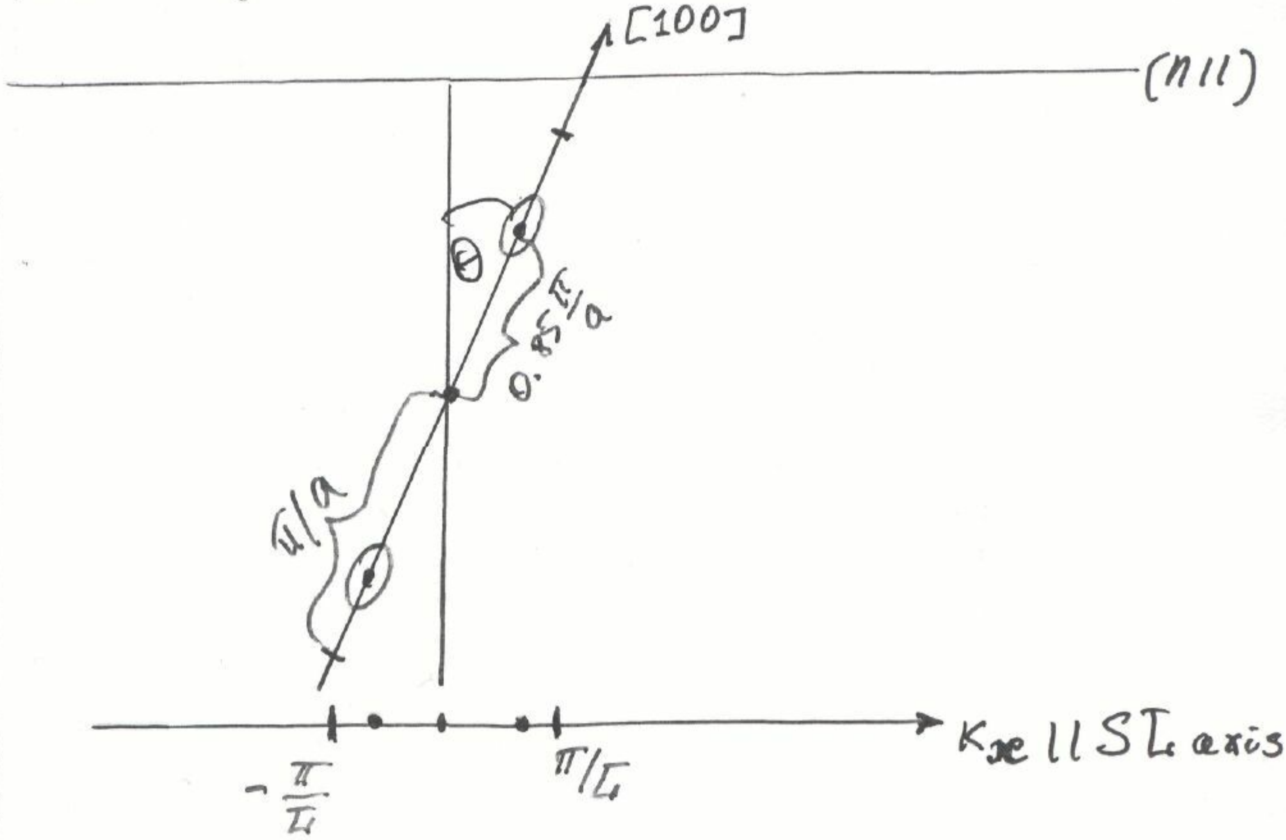
1. What is 2DES near vicinal silicon surface? History.
2. Energy spectrum. Superlattice. Density of states. Fermi surface. Topological transitions. Properties in quantized magnetic fields.
3. Anomalous state in QHE regime.
4. Linear longitudinal magnetoresistance. Spin susceptibility anomalies at topological transitions.
5. Conclusion. Electron-electron interaction and strong intervalley mixture induced by superlattice – the reasons of the observed anomalies. Questions to theory.

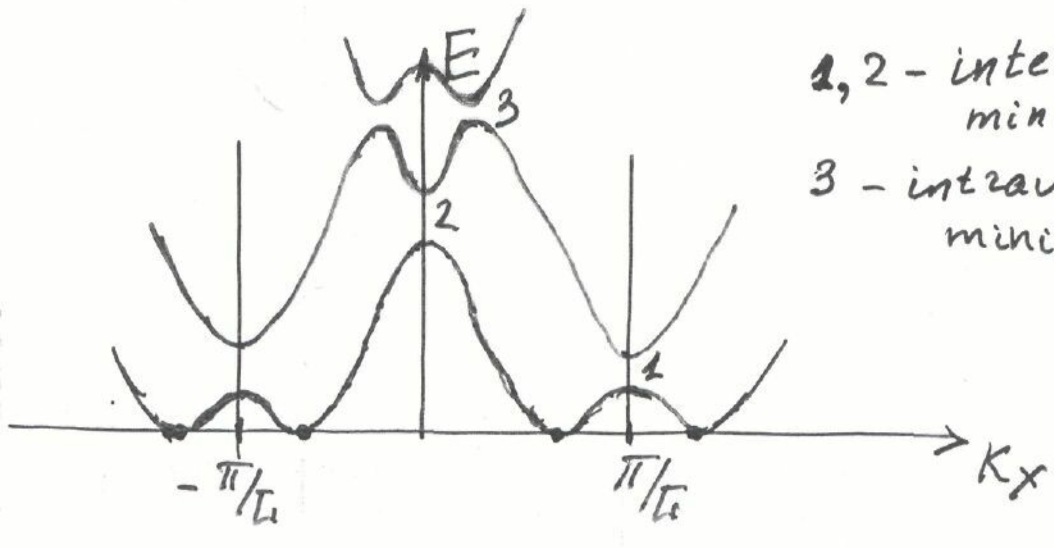
2D electron system near vicinal Si surface



$\Theta = \arccos n/\sqrt{n^2+1}$ $\quad L_1 = \dfrac{a}{2\cdot\sin\Theta}$ $\quad a = 5.43$ Å

usually $n = 8 - 10 \rightarrow \Theta = 8^\circ \div 10^\circ$





1, 2 - intervalley minigaps

3 - intravalley minigaps

History

1977 – Discovery of superlattice effects in 2DEG in vicinal Si-MOSFET
T.Cole, A.Lakhani, and P.J.Stiles, PRL, v.40, 744

1978 – The energy spectrum was constructed by Sham et al, PRL, v.40, 472
and Volkov and Sandomirskii, JETP Lett, v.27, 651

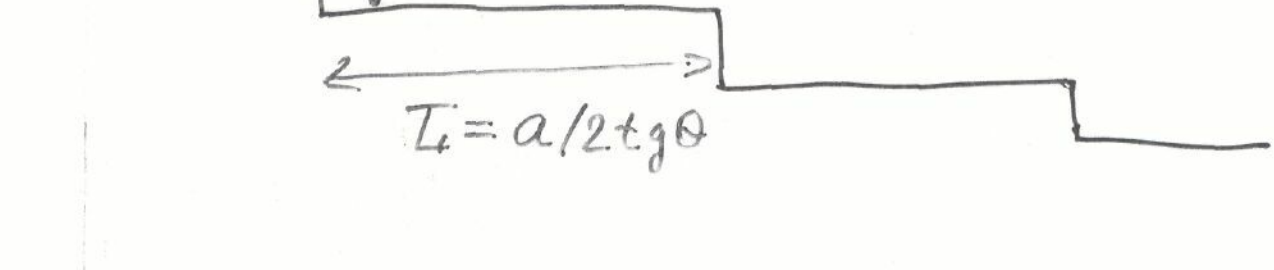
1981 – Superlattice effects were observed in 2DHS on vicinal surface near (111) silicon surface. So the superllatice is the universal property of silicon vicinal surface independently of the initial energy spectrum of 2DES.

Kvon et al, JETP Lett, v.

1993-2002 - All attempts to find superlattice effects in AlGaAs/GaAs, grown on vicinal GaAs surface. have failed

The origin of superlattice potential

Most probably it is a periodical system of steps by a height a/2 and terraces of the length $L = a/2\mathrm{tg}\theta$



Energy spectrum. Fermi surface. Density of states

$N_S = 2\cdot10^{12}$ $5\cdot10^{12}$

$\Delta = 2\,meV - 5\,meV$

$\Delta \simeq \alpha N_S$

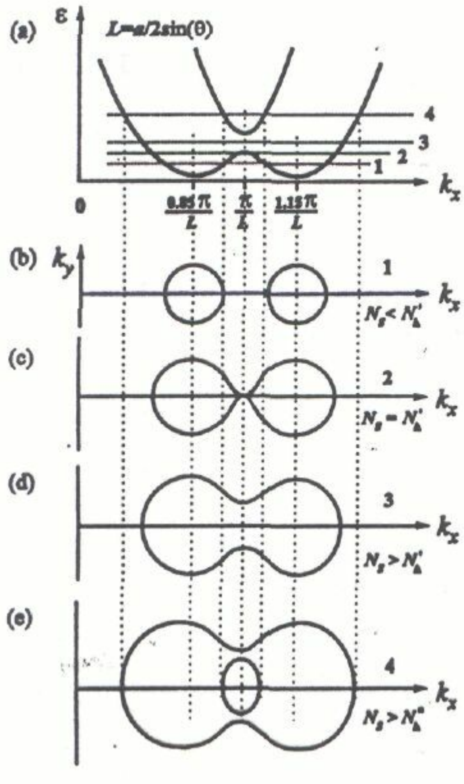
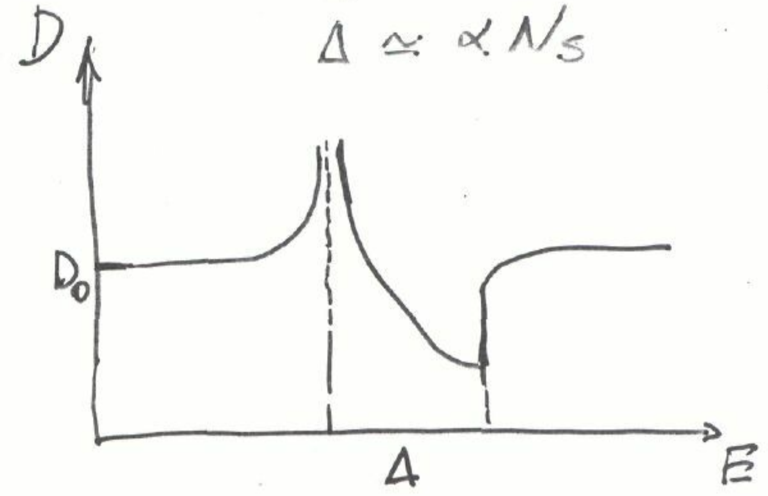
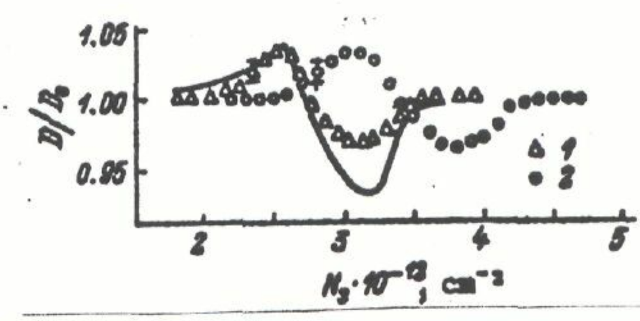
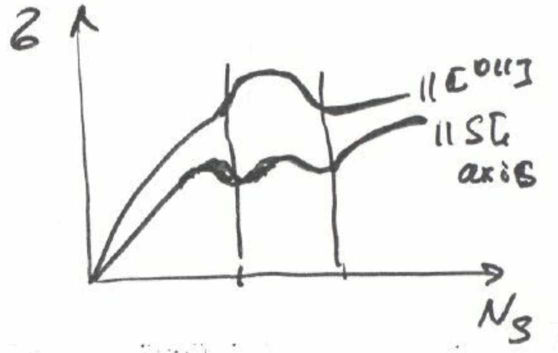


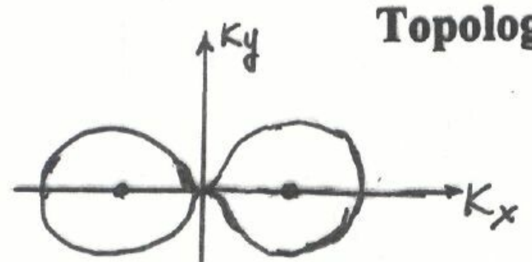
FIG. 4: (a) Typical dispersion relation for a 2DEG in a Si vicinal system[4]. (b-e) Isoenergy profiles at different positions of the Fermi level E_F marked by horizontal dotted lines in (a).



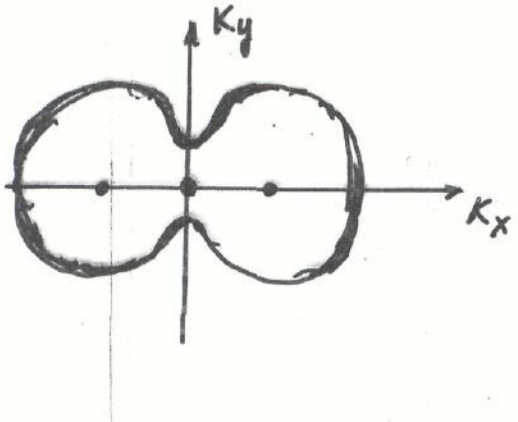




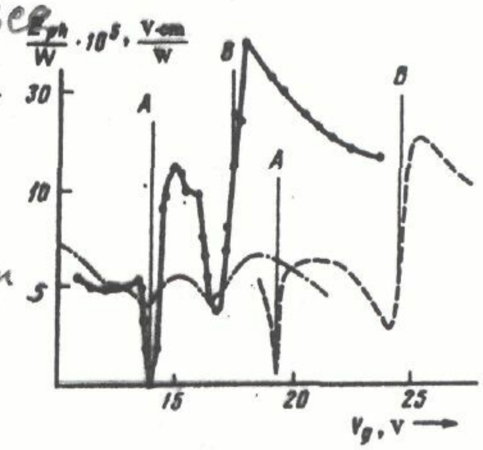
Topological transitions



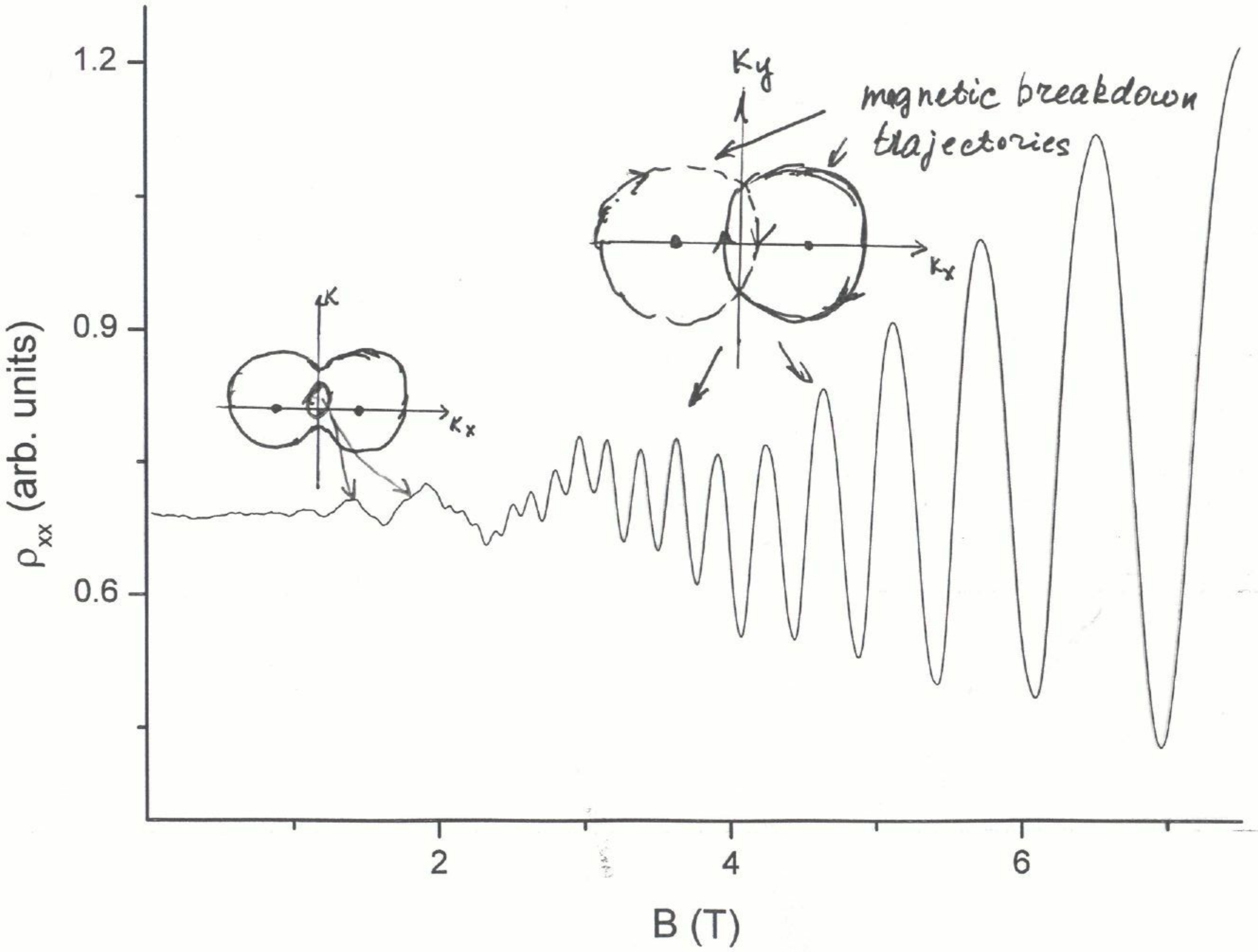
Two Fermi surfaces coalesce



Formation of a new FS



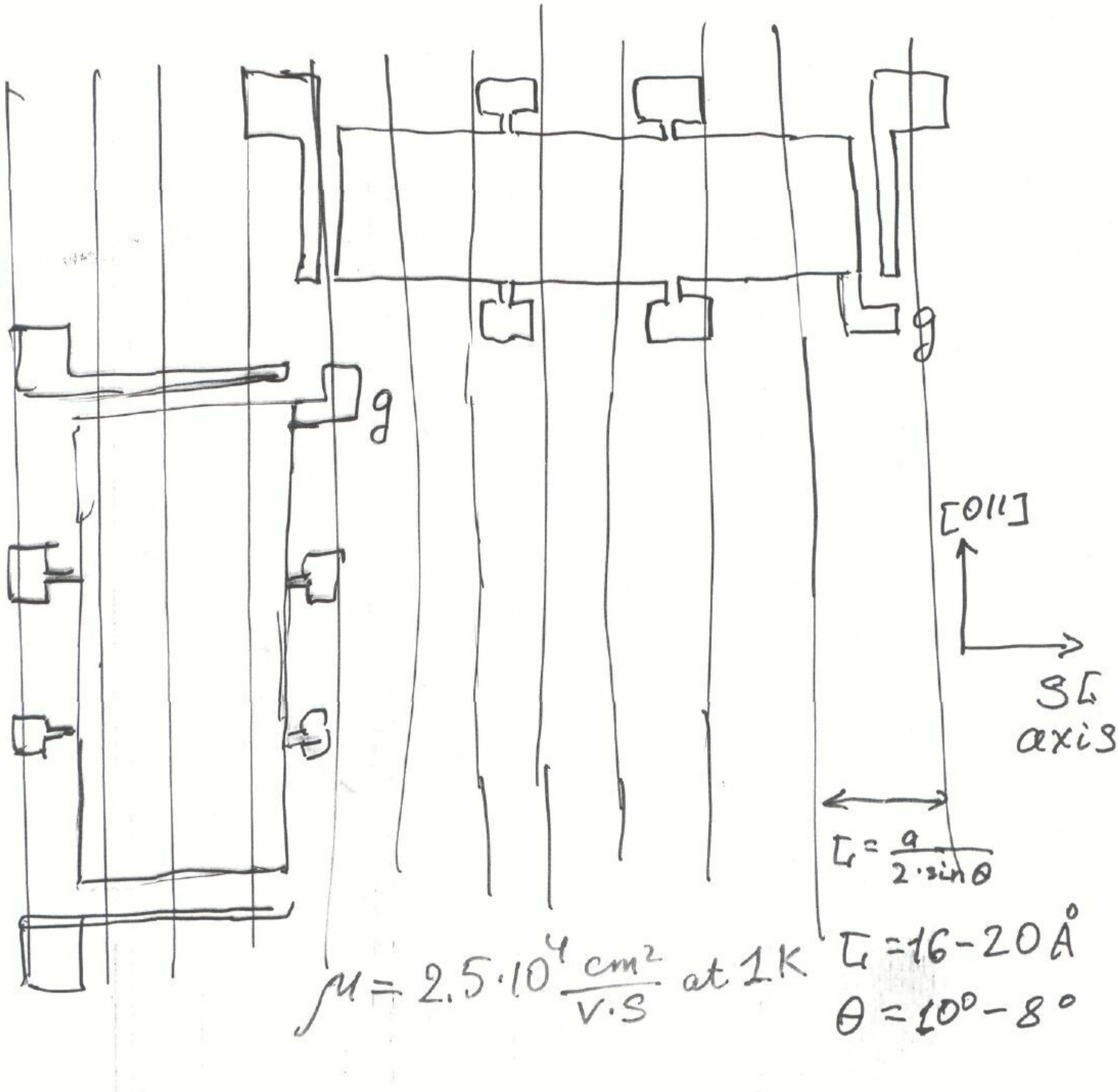
Zavaritskii, Kvon 1984

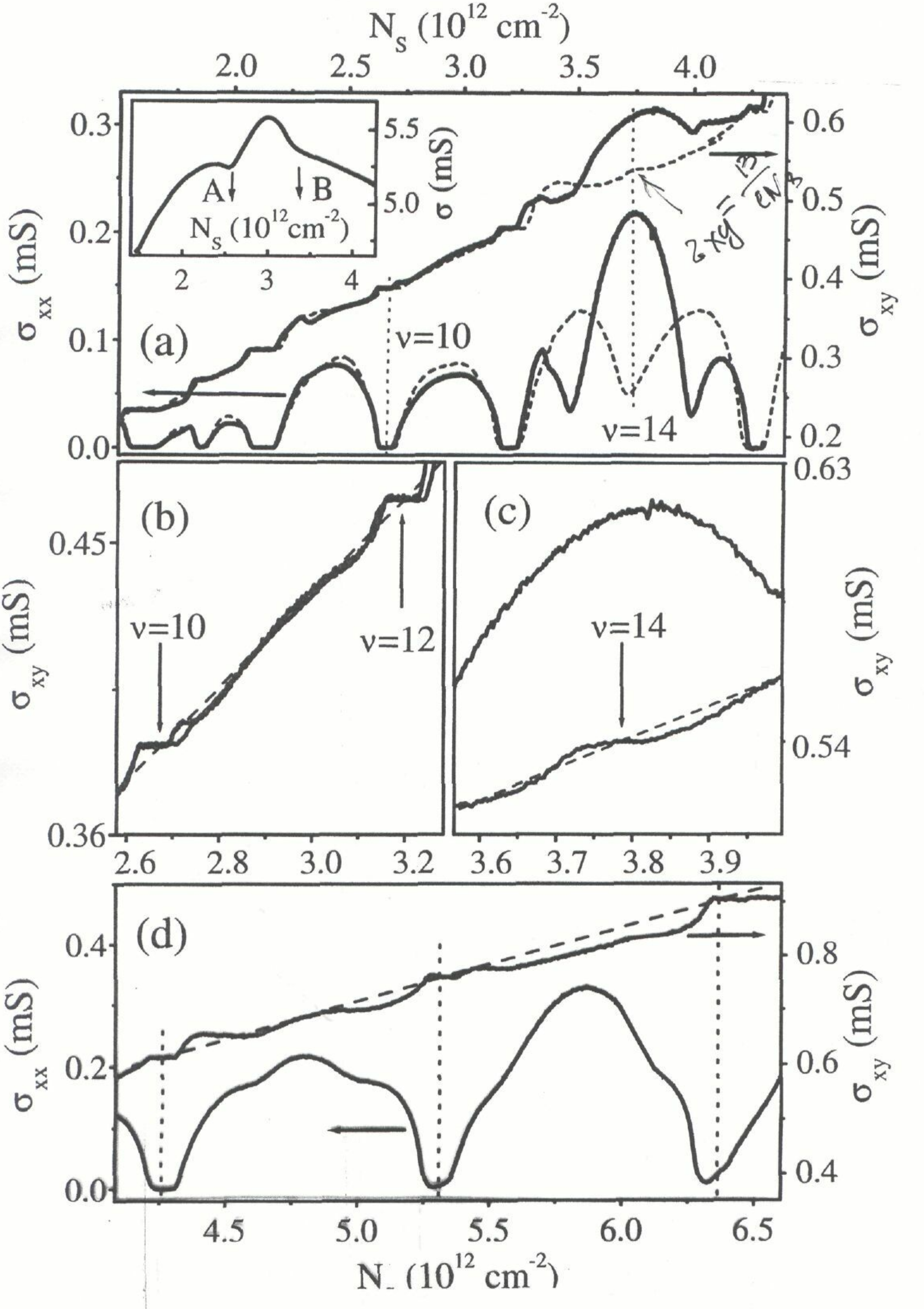


1.2
0.9
0.6
ρxx (arb. units)
2
4
6
B (T)
k
kx
ky
magnetic breakdown
trajectories

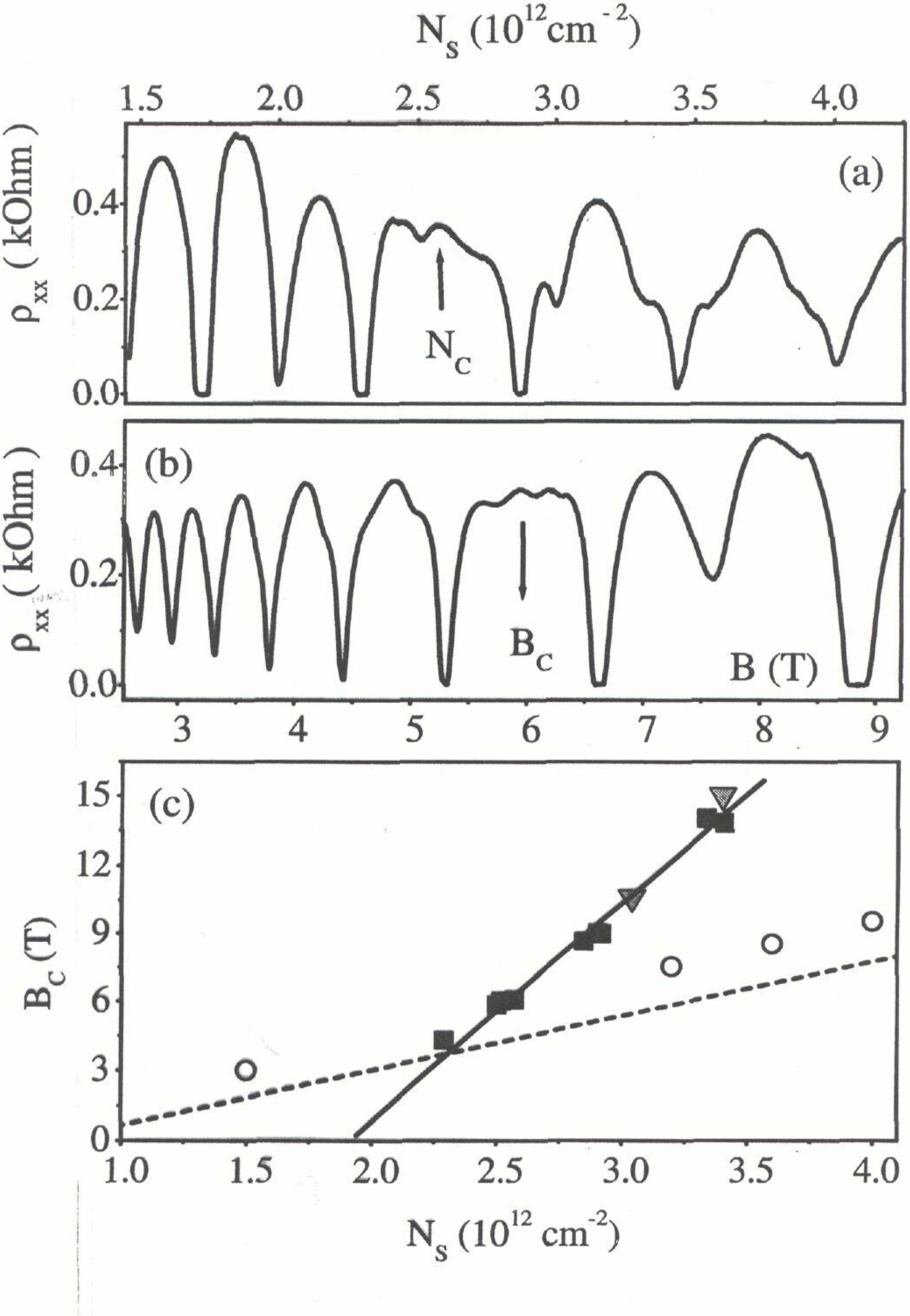
Samples

Si-MOSFET fabricated by means of conventional silicon technology on the wafers with the surface tilted by the angle 9.5° to (100) surface around the direction [001]



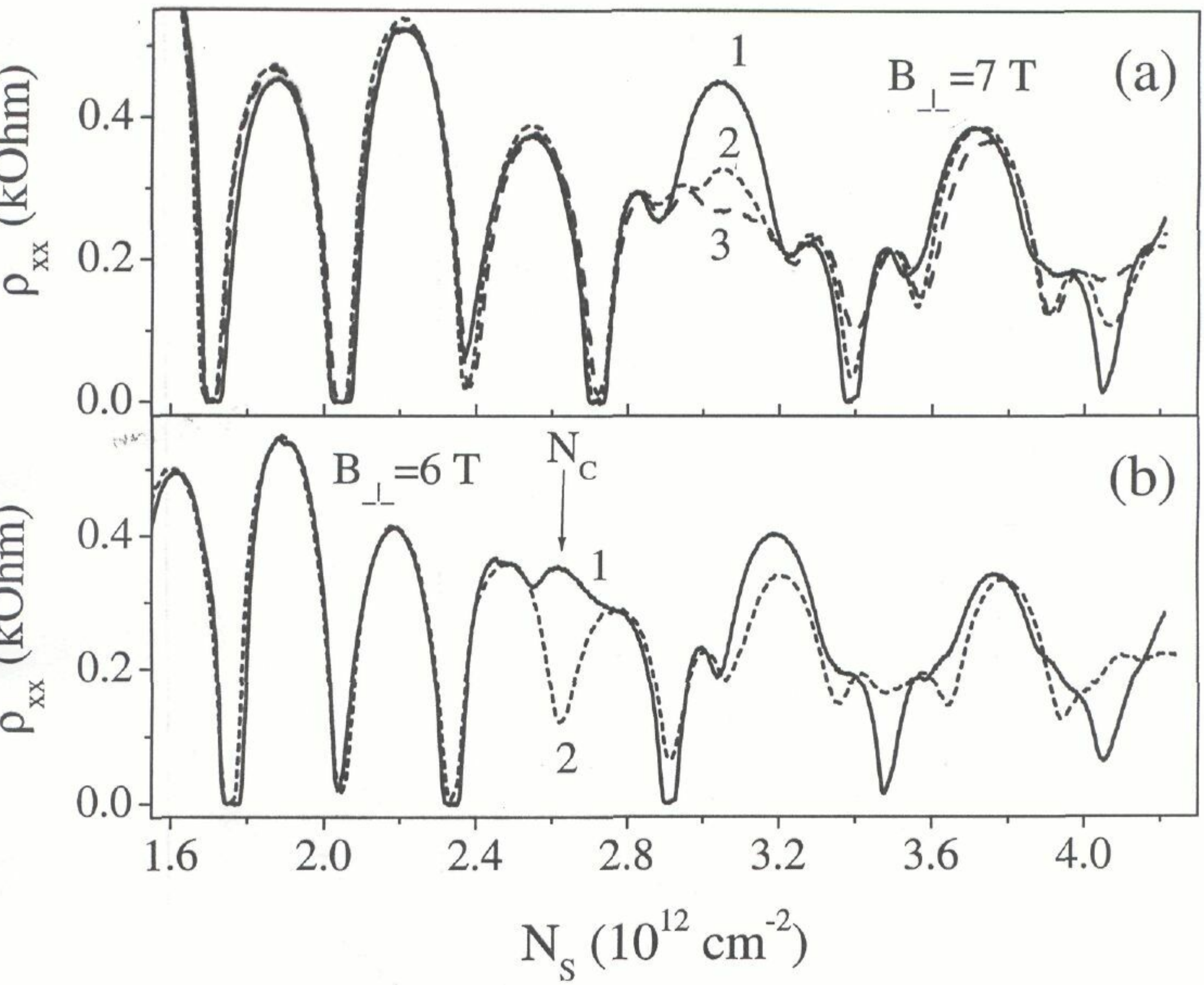


N_s (10^{12} cm^{-2})
2.0
2.5
3.0
3.5
4.0
0.3
0.2
0.1
0.0
σ_{xx} (mS)
0.6
0.5
0.4
0.3
0.2
σ_{xy} (mS)
A
B
5.5
5.0
σ (mS)
N_s (10^{12}cm^{-2})
2
3
4
(a)
ν=10
ν=14
(b)
(c)
0.45
0.36
σ_{xy} (mS)
ν=10
ν=12
ν=14
0.63
0.54
σ_{xy} (mS)
2.6
2.8
3.0
3.2
3.6
3.7
3.8
3.9
(d)
0.4
0.2
0.0
σ_{xx} (mS)
0.8
0.6
0.4
σ_{xy} (mS)
4.5
5.0
5.5
6.0
6.5
N_s (10^{12} cm^{-2})



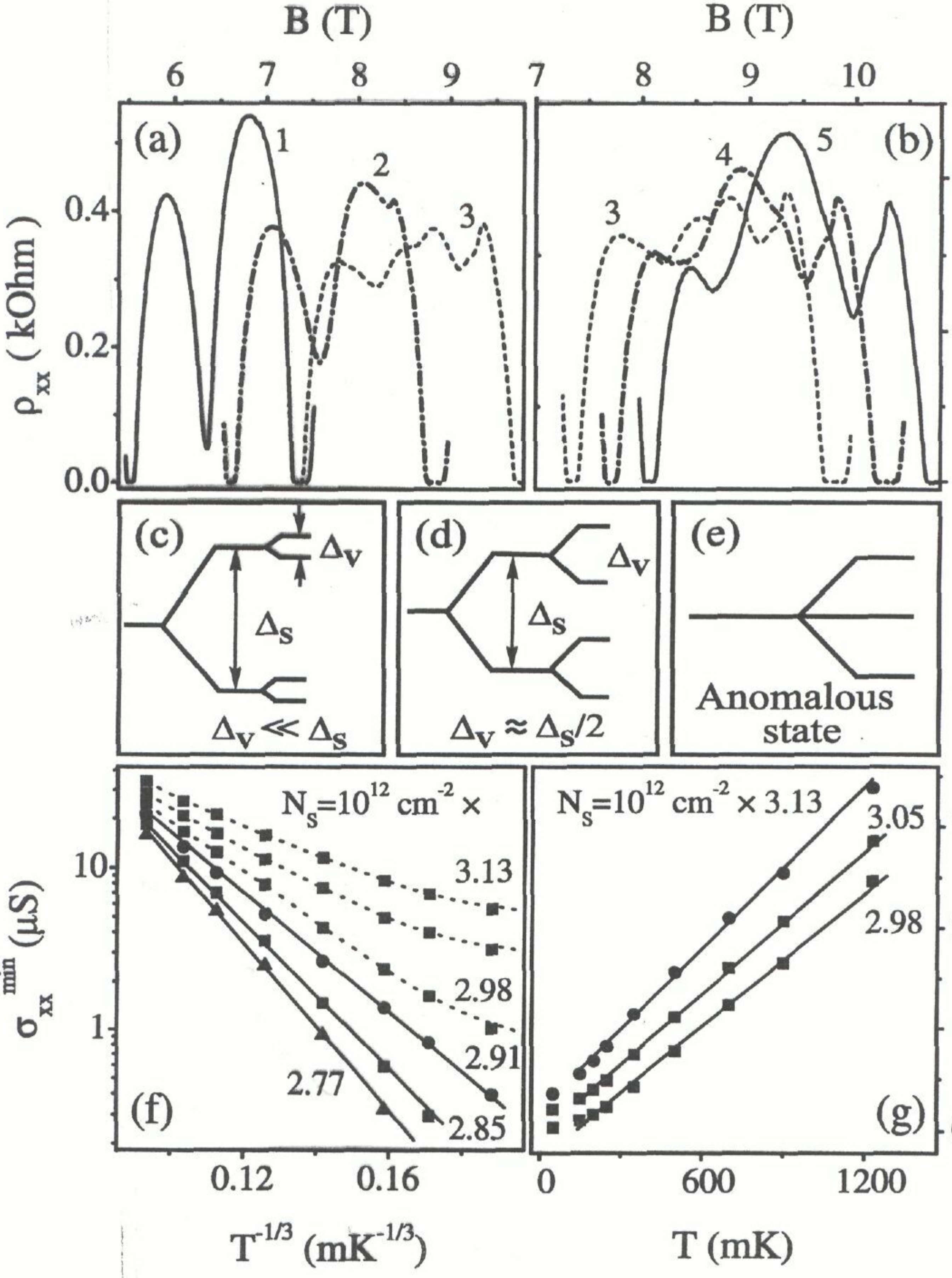
N_s (10^{12}cm^{-2})
1.5
2.0
2.5
3.0
3.5
4.0
(a)
ρ_{xx} (kOhm)
0.4
0.2
0.0
N_C
(b)
ρ_{xx} (kOhm)
0.4
0.2
0.0
B_C
B (T)
3
4
5
6
7
8
9
(c)
B_C (T)
15
12
9
6
3
0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
N_s (10^{12} cm^{-2})

1 - $B_{||}$=0 T
2 - $B_{||}$=5.87 T
3 - $B_{||}$=8 T

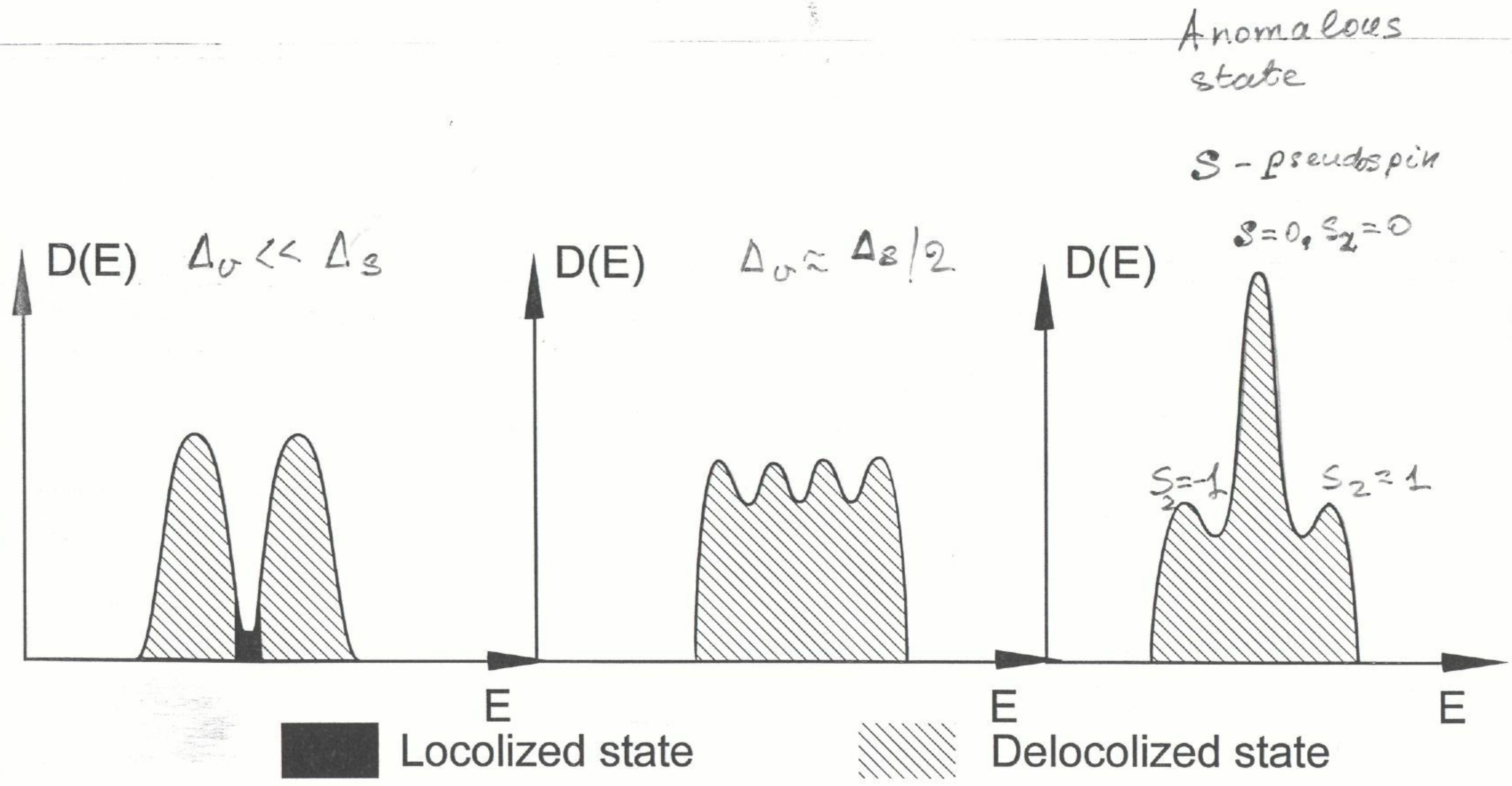


1 - $B_{||}$=0 T
2 - $B_{||}$=6.9 T

Fig. 4



B (T)
B (T)
6 7 8 9
7 8 9 10
(a)
(b)
1
2
3
3
4
5
ρxx (kOhm)
0.0 0.2 0.4
(c)
(d)
(e)
Δv
Δs
Δv ≪ Δs
Δv ≈ Δs/2
Anomalous state
σxx min (μS)
Ns=10^12 cm^-2 ×
3.13
2.98
2.91
2.85
2.77
Ns=10^12 cm^-2 × 3.13
3.05
2.98
(f)
(g)
0.12 0.16
0 600 1200
T^-1/3 (mK^-1/3)
T (mK)



Anomalous state
S - pseudospin
D(E)
$\Delta_v << \Delta_s$
D(E)
$\Delta_v \approx \Delta_s/2$
D(E)
$S=0, S_z=0$
$S_z=-1$
$S_z=1$
E
E
E
Locolized state
Delocolized state

Linear Magnetoconductance and Spin Susceptibility

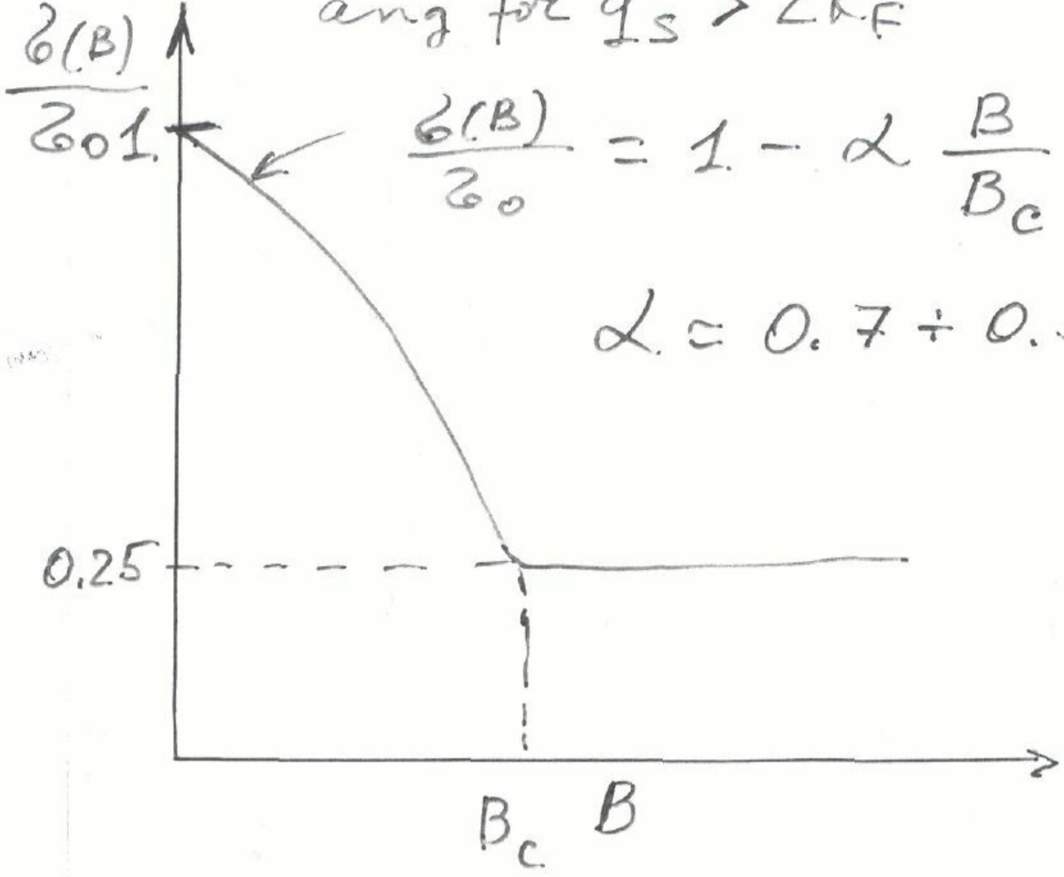
Gold-Dolgopolov screening model. MC originates from the change in the screening of scattering potential caused by the difference Fermi momenta for the two spin-split subbands

In the case of in impurity scattering

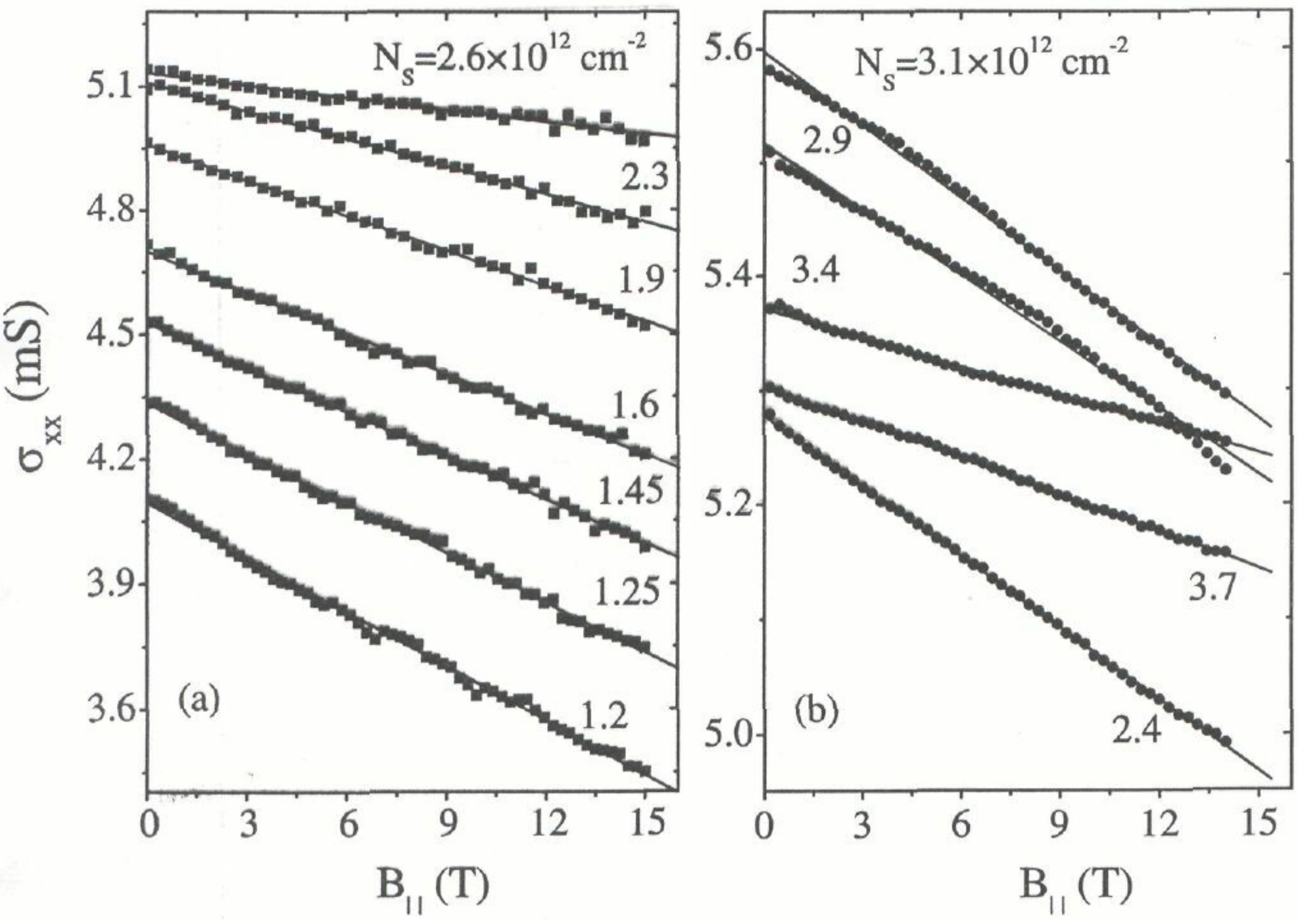
ang for $q_s > 2k_F$

$$\frac{\sigma(B)}{\sigma_0} = 1 - \alpha \frac{B}{B_c}$$

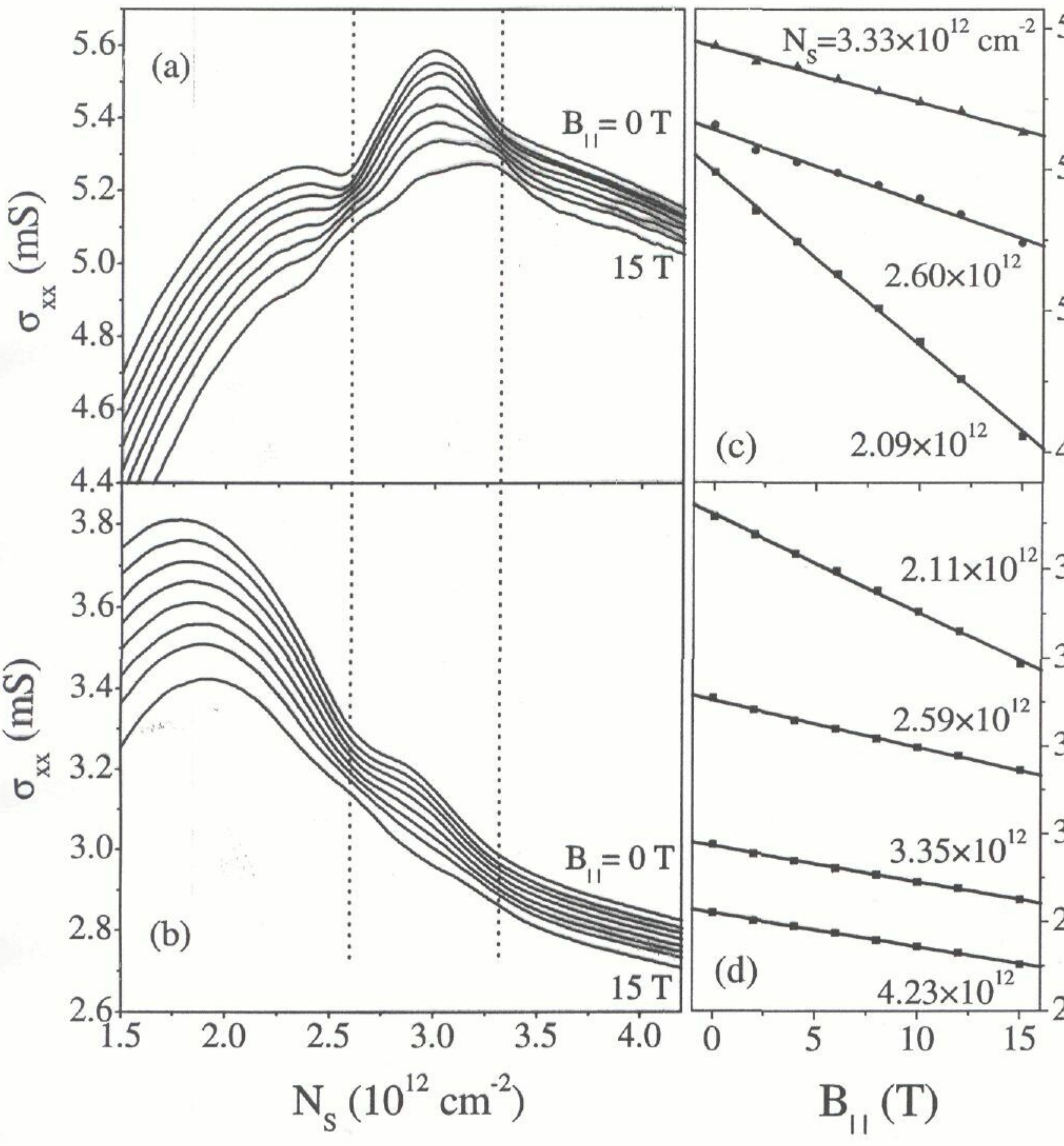
$$\alpha \simeq 0.7 \div 0.9$$



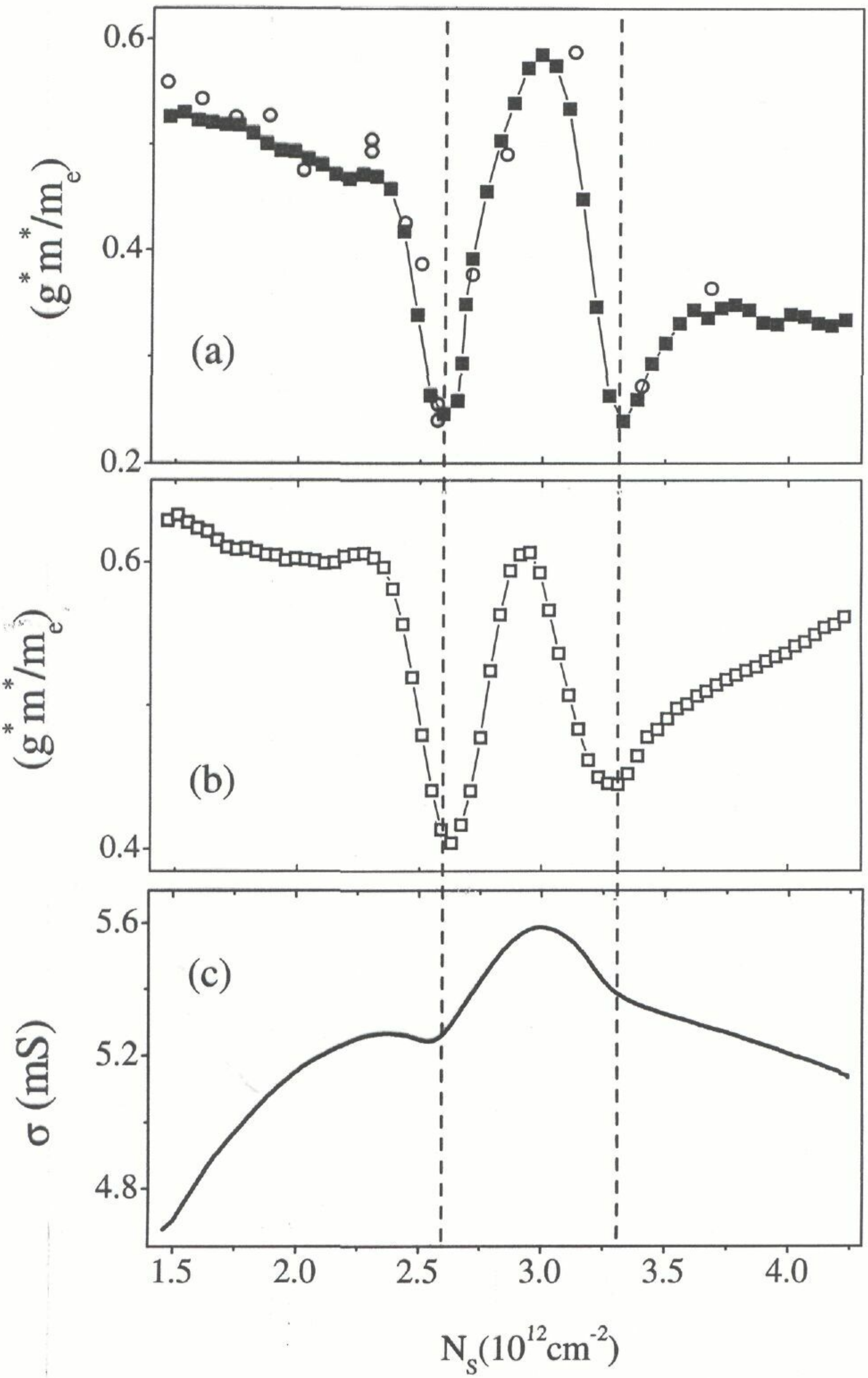
$$B_c = 2E_F / g^* \mu_B$$



N_s=2.6×10[12] cm[-2]
2.3
1.9
1.6
1.45
1.25
1.2
(a)
σ_{xx} (mS)
$B_{||}$ (T)
N_s=3.1×10[12] cm[-2]
2.9
3.4
3.7
2.4
(b)
$B_{||}$ (T)



(a)
(b)
(c)
(d)
σ_{xx} (mS)
σ_{xx} (mS)
$B_{||}$ = 0 T
15 T
$B_{||}$ = 0 T
15 T
N_s=3.33×10^12 cm^-2
2.60×10^12
2.09×10^12
2.11×10^12
2.59×10^12
3.35×10^12
4.23×10^12
N_S (10^{12} cm^{-2})
$B_{||}$ (T)



0.6
0.4
0.2
(g*m*/m_e)
(a)
0.6
0.4
(g*m*/m_e)
(b)
5.6
5.2
4.8
σ (mS)
(c)
1.5
2.0
2.5
3.0
3.5
4.0
N_S(10^12cm^-2)

Conclusion

1. The anomalous state of 2DES near vicinal Si surface in QHE regime has been observed. It is characterized by unusual behavior of the conductivities σ_{xx} and σ_{xy}, which can be described as collapse of the Zeeman splitting accompanied by large peak in σ_{xx} and anomalous peak in Hall conductivity σ_{xy} dependences on magnetic field and electron density.

2. An unusual, linear MC was observed in 2DES on vicinal Si surface. It is well described by recent screening model of Gold-Dolgopolov. Spin susceptibility determined from the slope of linear dependence agrees well with previous results for (100) at $N_s < N_\Delta^1$. The strong anomalies of this susceptibility were detected at the points of topological transitions.

3. We suggest that the anomalies we observed are due to electron-electron interaction and strong intervalley mixture induced by superlattice potential.

Questions to theory

1. Whether the spin-collapsed state in QHE regime is unknown trivial fact or the signature of nontrivial state induced by electron-electron interaction and strong intervalley mixture?

2. How should spin susceptibility behave at topological transitions in Fermi system with strong intervalley mixture.